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CERL'S FUME TESTING FACILITY FOR EXPLOSIVES
PART 1: DESIGN AND EVALUATION OF EXPLOSION CONTAINMENT VESSEL

E. Contestabile, D. Cox, T.R. Craig and D. Hamel
Canadian Explosives Research Laboratory

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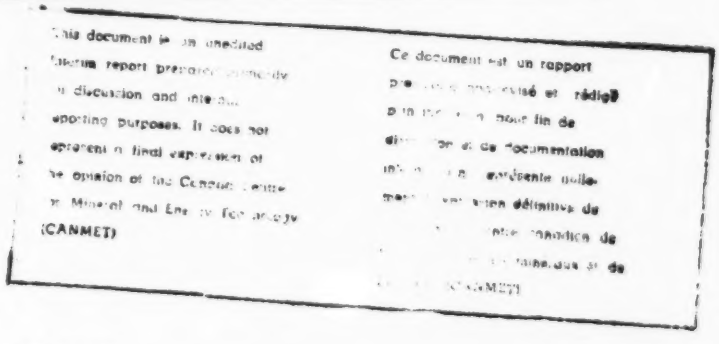

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by

E. Contestabile*, D. Cox**, T.R. Craig**, and D. Hamel**

ABSTRACT

Explosion containment vessels were designed to simulate one to be used in a fume testing facility. The vessels were made of two coaxial, cylindrical steel containers separated by a thickness of rubber. An explosive charge was placed in the center of the vessel surrounded by sand or other material. Depending on the explosive sample configuration, some vessels were tested in excess of twenty shots with satisfactory results.

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*Physical Scientist, **Explosives Technologist, Canadian Explosives Research Laboratory, Mining Research Laboratories, CANMET, Energy, Mines and Resources Canada.

INSTALLATION D'ESSAI DE FUMÉES DE TIR POUR LES EXPLOSIFS AU LCRE
PARTIE 1: CONCEPTION ET ÉVALUATION DU RÉCIPIENT DE CONFINEMENT D'EXPLOSIONS

par

E. Contestabile*, D. Cox**, T.R. Craig** et D. Hamel**

RÉSUMÉ

Les récipients de confinement d'explosions ont été conçus afin de simuler un récipient qui sera utilisé dans une installation d'essai de fumées de tir. Les récipients sont fabriqués à partir de deux récipients coaxiaux cylindriques en acier, séparés par une épaisseur de caoutchouc. Une charge d'explosifs a été placée au centre du récipient entouré de sable ou d'autres matériaux. Selon la configuration de l'échantillon d'explosifs, certains récipients ont été soumis à des essais comportant plus de vingt détonations avec des résultats satisfaisants.

*Physicien, **Technologistes des explosifs, Laboratoire canadien de recherche sur les explosifs, Laboratoires de recherche minière, CANMET, Énergie, Mines et Ressources Canada.

TABLE OF CONTENTS

	Page
ABSTRACT	i
RÉSUMÉ	ii
INTRODUCTION	1
Test vessel #1 - Rubber hardness 50-55 shore A duro	4
Test vessel #2 - Rubber hardness 50-55 shore A duro	4
Test vessel #3 - Rubber hardness 50-55 shore A duro	7
Test vessel #4 - Rubber hardness 50-55 shore A duro	7
Test vessel #5 - Rubber hardness 75 shore A duro	8
Test vessel #6 - Rubber hardness 50-55 shore A duro	9
CONCLUSIONS	13

FIGURES

1.	Fume testing facility	2
2.	Explosion containment vessel	1
3.	Plan of test container	3
4.	Details of rubber disc and rings	3
5.	Test vessel loaded with sand and one cartridge of explosive (Test 1-1)	4
6.	Result of detonating three cartridges of explosive in sand test (Test 1-3)	4
7.	Test vessel loaded with sand and two cartridges of explosive (Test 2-2)	5
8.	Photograph of test vessel loaded with three cartridges of Dynamite end-to-end (Test 2-3)	5
9.	Test vessel loaded with sand and two cartridges of explosive confined in a steel pipe (Test 2-4)	5
10.	Damage to confining steel pipe due to the detonation of two cartridges of explosive (Test 2-4)	6
11.	Inner container without bottom and rubber rings still attached (Test 2-7)	6
12.	Fracture of bottom weld on the inner container (Test 2-7)	6
13.	Bulged inner container (Test 2-7)	7
14.	Split inner container (Test 3-2)	7
15.	Typical set-up for the tests performed on vessel #4	7
16.	Result of detonating two cartridges of explosive confined in a steel pipe (Test 5-29)	10
17.	Cross-section of vessel #6	10
18.	Deformation of steel ring (Test 6-12)	10
19.	One steel rod partially pulled out (Test 6-14)	12
20.	Steel ring blown off the container (Test 6-15)	12
21.	Vessel #6 showing the two bulges	12
22.	Details of vessel #6 cut in two	12

TABLES

No.		Page
1.	Endurance test results for vessel #4	8
2.	Endurance test results for vessel #5	9
3.	Endurance test results for vessel #6	11

INTRODUCTION

The Canadian Explosives Research Laboratory (CERL), is in the process of designing a new test facility for the evaluation of the fumes produced by detonating commercial explosives. Part of the facility is shown in Fig. 1, with details of the explosion containment vessel shown in Fig. 2. This vessel, which has been designed to withstand explosions of about 1 kg of dynamite, is the concern of this report. Due to its high cost, it is imperative that it be protected against any damage.

A definite test sample configuration has not yet been established, however, since tests may be performed with the explosives confined in metal pipes, in sand, or in crushed stone, there will be shrapnel and other debris that will cause damage to the vessel. Therefore precautions must be taken to protect its internal surface from being pitted or deformed. A series of tests were designed to:

1. determine the test method of protecting the explosion vessel,
2. establish the test sample configuration
3. determine the number of tests that the vessel could tolerate before any deformation of the inside wall occurred.

Since it is impossible to completely avoid damage, it was decided that a sacrificial inner container should be used. This could be easily replaced if damaged. Furthermore, it would be beneficial if this inner liner was isolated from the container by a shock-absorbing material.

Since the liner would deform during use, it was anticipated that this could cause a problem when replacement was required. Thus, it was necessary to also determine the force required to pull the liner and the shock absorbing material from the outer container.

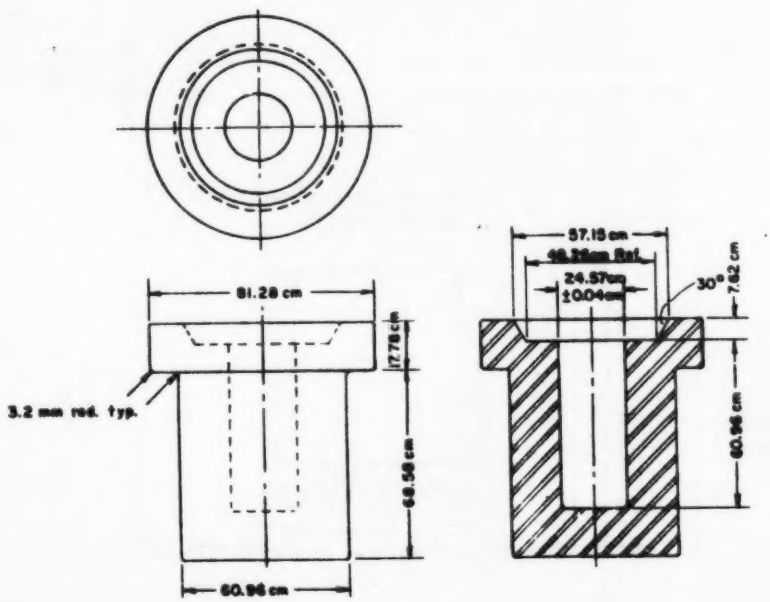


Fig. 2 - Explosion containment vessel

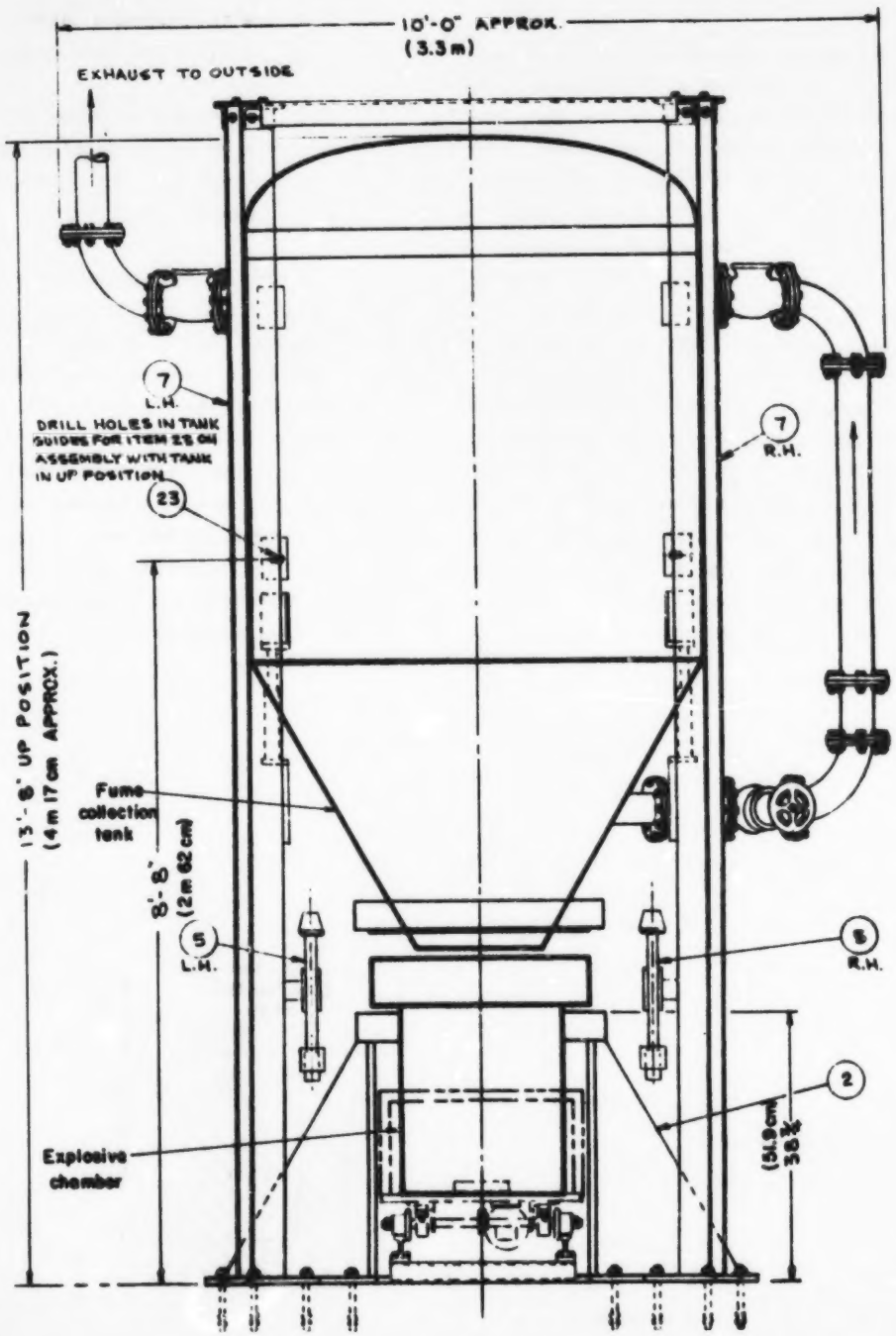
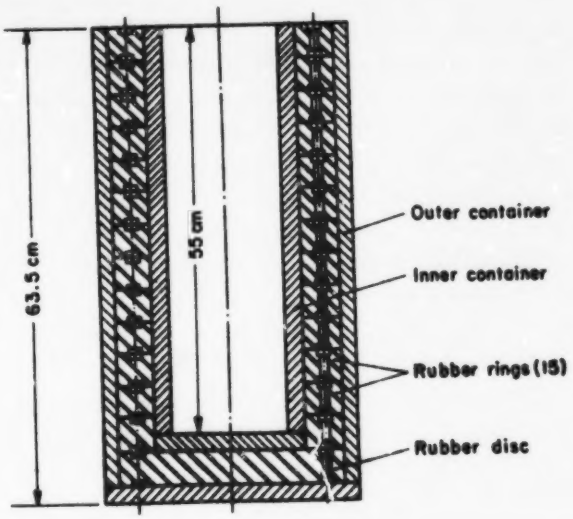


Fig. 1 - Fume testing facility

Figure 3 shows a sketch of the test container used to evaluate the explosion containment vessel. It is comprised of two, thick-walled cylindrical steel containers, separated from each other by a disc and rings made of natural rubber. Details of these items are shown in Fig. 4. The natural rubber used was 50-55 or 75 Shore A Duro hardness.



Inner tube – 12.70cm ID and 1.905cm wall
Outer tube – 27.94cm OD and 1.670cm wall

Fig. 3 - Plan of test container

The test vessels were assembled as follows. With the outside container mounted on a lathe and using a soapy water solution as lubricant, the bottom rubber disc and rings were lightly wetted and pushed into it. Rings were added to completely fill this container. Then, the inner container was aligned with the inside of the rubber rings and pressed in with the lathe's tailstock.

A series of tests was performed on each vessel. To determine the cumulative effect of each trial, the vessel was tested in the condition that it was left in by the previous test. If any of the rubber rings popped out they were not replaced. However, if any parts of the vessel, such as the rubber disc or rings or the outer container, survived the testing, they were reused. Several vessels were tested for endurance. The purpose of this series was to determine the number of shots that the vessel could tolerate without incurring any damage to the outer container.

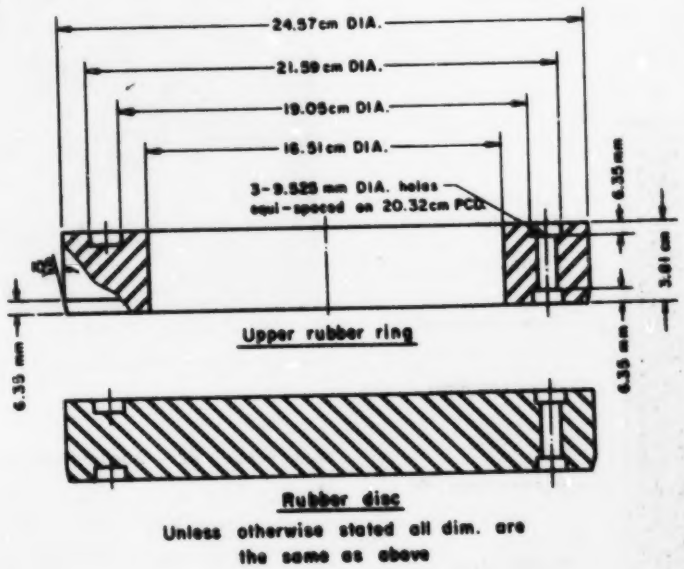


Fig. 4 - Details of rubber disc and rings

The explosive used in these tests was either Canagel 40 Tamptite, Hercodyne Sp, or Dynamite B-40% in 2.5 cm diameter by 20 cm long or 3.2 cm diameter by 20 cm long cartridges weighing about 175 g and 220 g each respectively. All shots were top primed.

Test vessel #1 - Rubber hardness 50-55 Shore A Duro

Test 1-1: The vessel was assembled as outlined and set upright on the ground in the testing area. It was then filled halfway with 24 grit silica sand. A 3.2 cm diameter cartridge of dynamite primed with an electric detonator was centered in the container and more sand was added to completely fill the vessel. This set-up is shown in Fig. 5. The explosive was then detonated. The blast caused some of the sand to be shot upward. The vessel, however, having incurred no visible damage and remained standing. Most of the sand that remained in the container, some of which had been fused together by the blast, was emptied and measurements were taken. The inner diameter at its midpoint showed an increase from 12.7 cm to 13.0 cm.

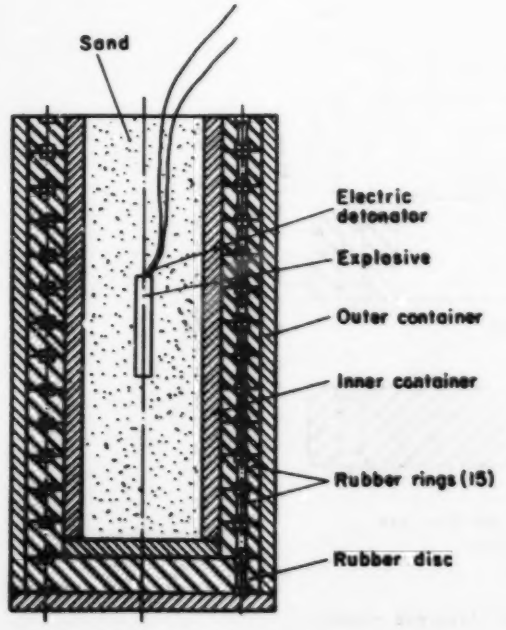


Fig. 5 - Test vessel loaded with sand and one cartridge of explosive (Test 1-1)

Test 1-2: The test vessel was again prepared in the manner described above with only the amount of explosive being varied. Two 3.2 cm diameter cartridges of dynamite were taped side-by-side and centered in the vessel. The detonation of this explosive caused approximately half of the sand to spray upward and the uppermost rubber ring to pop out. Again, the vessel remained standing with no visible damage incurred by the outer container. The remaining sand was poured out and observations were made. The bulge in the inner container had increased to 14.1 cm in diameter.

Test 1-3: Test vessel #1 was again prepared varying only the amount of explosive. Three 3.2 cm diameter cartridges of dynamite were taped side-by-side and centered in the vessel. The detonation of this explosive caused both the inner and outer containers to rupture. Figure 6 shows the pieces that were recovered. Most of the rubber rings were destroyed but the bottom disc survived.

Fig. 6 - Result of detonating three cartridges of explosive in sand test (Test 1-3)

Test vessel #2 - Rubber hardness 50-55 Shore A Duro

Test 2-1: This test was identical to the first one performed on test vessel #1. The explosion caused the inner container to bulge slightly from the original 12.7 cm diameter to 12.9 cm diameter. The uppermost rubber ring was pushed out a distance of 2 cm from its original position.

Test 2-2: Test vessel #2 was prepared as described above with two, 3.2 cm diameter cartridges of dynamite taped end-to-end and centered in the vessel. This set-up is shown in Fig. 7. The detonation of this explosive caused about two thirds of the sand to be blown out. This was accompanied by a 1.5 cm movement of the rubber rings and of the inner steel container out of the outer container. The explosion caused the bulge to increase slightly to 13.2 cm.

Test 2-3: Three 3.2 cm diameter cartridges of explosive were taped end-to-end and

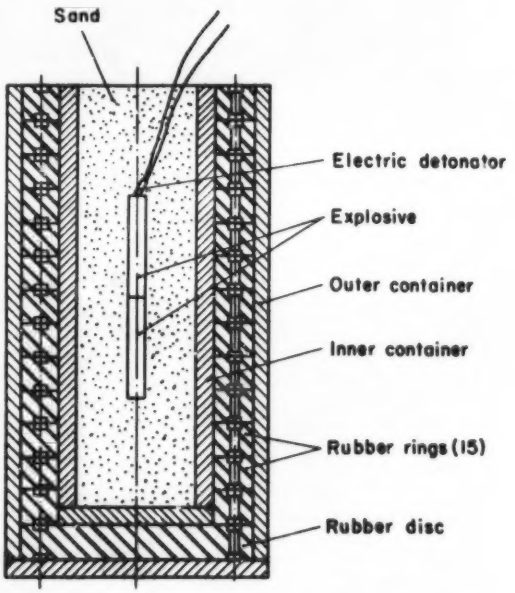


Fig. 7 - Test vessel loaded with sand and two cartridges of explosive (Test 2-2)

placed in the container. The overall length of the explosive was longer than the container so that part of it was not covered by the sand. Figure 8 is a photograph of this assembly. The explosion of this charge blew one ring out and pushed the inner container so that its top was 1 cm above the top of the outer container. The bulge also enlarged to a 13.4 cm diameter.

Test 2-4: This test was similar to Test 2-2 except that the two, 3.2 cm diameter explosive cartridges were confined in a steel pipe having an outside diameter of 4.22 cm and an inside diameter of 3.25 cm. This assembly is shown in Fig. 9. On

Fig. 8 - Photograph of test vessel loaded with three cartridges of Dynamite end-to-end (Test 2-3)

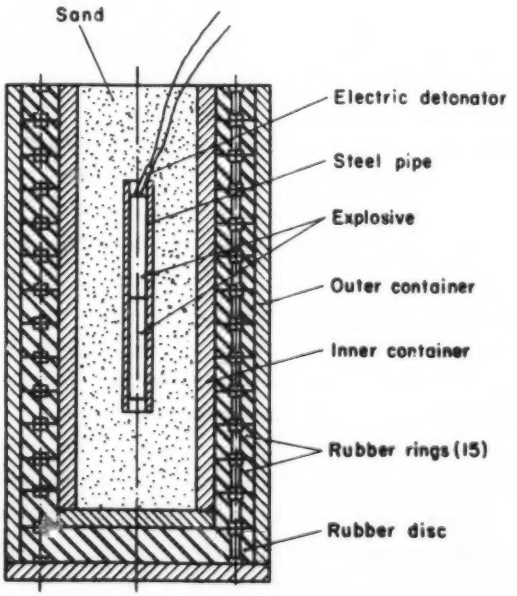


Fig. 9 - Test vessel loaded with sand and two cartridges of explosive confined in a steel pipe (Test 2-4)

detonating the explosive, the torn pipe, and some sand were blown out. Figure 10 shows the damage incurred by the confining pipe. The diameter of the bulge of the inside container increased to 13.6 cm diameter.

Fig. 10 - Damage to confining steel pipe due to the detonation of two cartridges of explosive (Test 2-4)

Test 2-5: This was a repeat of Test 2-4. The explosion caused the top rubber ring to partly blow out and the bulge to expand to 14.2 cm diameter. The steel pipe ruptured as in Test 2-4. Also, the inner container was pushed back to its original position.

Test 2-6: This test was also a repeat of Test 2-4. The detonation of the charge caused the next rubber ring to blow off and the bulge to increase to 14.5 cm diameter. The confining steel pipe was again shattered as in the previous tests and the inner container was pushed out 1 cm above the surface of the outer container.

Test 2-7: In this test, 1 cm crushed stone was substituted for the sand and the explosive was loaded as in Test 2-4. The explosion caused the inner container and most of the rubber rings to blow out and land 8 m away. Figure 11 shows the ejected inner container with most of the rings still attached. As shown in Fig. 12, the explosion caused brittle fracture of the weld at the bottom of the inner container. On examination, the diameter of the bulge had increased to 14.7 cm and fine cracks were discernible on the outside surface. Figure 13 shows the bulged inner container. The confining pipe that was ejected along with the crushed stone was shattered to several pieces. The bottom of the outer container suffered some deformation, however, the cylinder itself remained intact.

Fig. 11 - Inner container without bottom and rubber rings still attached (Test 2-7)

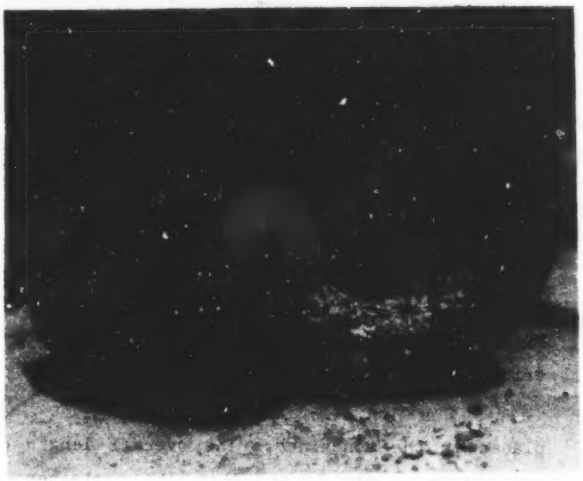


Fig. 12 - Fracture of bottom weld on the inner container (Test 2-7)

Fig. 13 - Bulged inner container (Test 2-7)

Test vessel #3 - Rubber hardness 50-55 Shore A Duro

Test 3-1: This test was identical to Test 2-7. It was repeated because it was suspected that there was an air gap between the rubber disc and the bottom of the inner container in Test 2-7. The fractured weld would then have resulted due to the lack of physical support. On detonation, a cloud of dust shot up from the container. The explosive caused the confining pipe to enlarge and embed itself in the pulverized crushed stone. The top rubber ring moved up slightly on one side but the inner container did not move. The weld at the bottom of this container was not damaged, however, the inside diameter bulged by 4 mm to 13.1 cm.

Test 3-2: This test was a repeat of Test 3-1. The explosion caused the two top rubber rings to be blown out and the inner container to split lengthwise. The split container is shown in Fig. 14. No damage was done to the outer container or to the rubber rings.

Test vessel #4 - Rubber hardness 50-55 Shore A Duro

The following series of tests were performed to determine the endurance of a particular vessel to repetitive shots. Each round was loaded with two cartridges of the 2.5 cm diameter explosive confined in a steel pipe having inner and outer diameters of 2.6 cm and 3.3 cm respectively. Figure 15 shows a typical shot ready for firing. The first five shots were done with the 24 grit silica sand while the rest were repeated with either 12 grit foundry sand (Tests 4-6 to 4-23) or construction grade sand (Tests 4-24 to 4-30).

Fig. 14 - Split inner container (Test 3-2)

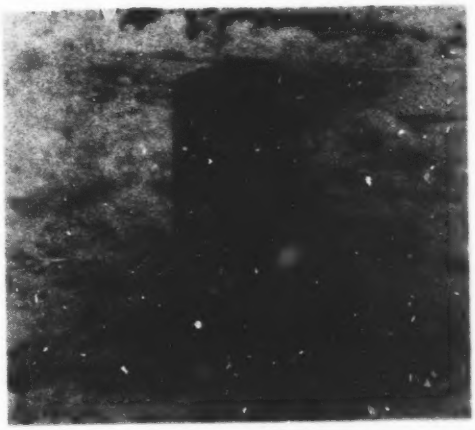


Fig. 15 - Typical set-up for the tests performed on vessel #4

As testing progressed, the inside of the vessel started developing two distinctive bulges that corresponded to the centre of each cartridge of explosive. The bulges were not always symmetric, therefore, the diameters reported are of the largest dimension. Table 1 summarizes these results. No damage was incurred by the outer container.

Table 1 - Endurance test results for vessel #4

Test #	Diameter Top Bulge (cm)	Diameter Bottom Bulge (cm)	Comments
4-1	12.8		
4-2	12.9		
4-3	13.2		1st rubber ring moving up
4-4	13.3		1st ring loose
4-5	13.4		1st ring in same position
4-6	13.6		1st ring blown off
4-7	13.7		
4-8	13.9		2nd ring rising
4-9	14.1		
4-10	14.3		2nd ring flush with top
4-11	14.5		
4-12	14.7		
4-13	14.8		
4-14	15.1	15.2	
4-15	15.2	15.4	
4-16	15.4	15.5	
4-17	15.7	15.7	
4-18	15.8	15.8	
4-19	15.8	15.9	2nd ring blown off
4-20	15.9	16.0	
4-21	16.1	16.2	
4-22	16.3	16.4	
4-23	16.6	16.6	
4-24	16.6	16.7	
4-25	16.6	16.7	
4-26	16.6	16.8	
4-27	16.6	16.9	
4-28	16.7	17.1	
4-29	16.9	17.2	
4-30	16.9	17.2	

After shot 4-30 the inside diameter of the inner vessel had increased from 12.7 cm to 17.2 cm. At this time it was decided to determine what force would be required to pull the inner container from the outer.

A steel plate was bolted to the top of the inner container so that a hook could be attached to it. Then using an hydraulic press a load was applied so that the two containers would be pulled apart. A 170 MPa (2500 psi) pressure on a 10.16 cm (4 in.) diameter ram was required to do the job. Thus the force required to separate the containers was 1.38 N (31.4 Kpsi).

Test vessel #5 - Rubber hardness 75 Shore A Duro

The following series of tests were again performed to determine the endurance of the vessel to repeated shots. The vessel was assembled with harder rubber rings but with the same hardness rubber disc. The test set-up was the same as that

Table 2 - Endurance test results for vessel #5

Test #	Diameter Top Bulge (cm)	Diameter Bottom Bulge (cm)	Comments
5-1	12.8	12.8	
5-2	12.9	13.0	
5-3	13.1	13.1	1st rubber ring blown off
5-4	13.4	13.4	
5-5	13.4	13.4	
5-6	13.5	13.6	
5-7	13.7	13.7	
5-8	13.8	13.8	
5-9	13.9	14.0	
5-10	14.1	14.1	
5-11	14.2	14.1	
5-12	14.2	14.2	
5-13	14.4	14.5	
5-14	14.6	14.6	
5-15	14.9	14.7	
5-16	15.0	15.1	
5-17	15.1	15.2	2nd ring blown off
5-18	15.2	15.2	
5-19	15.2	15.3	
5-20	15.3	15.6	
5-21	15.6	15.8	
5-22	15.8	15.9	
4-23	15.9	15.9	
5-24	16.0	16.1	
5-25	16.3	16.2	
5-26	16.5	16.5	
5-27	16.8	16.6	
5-28	16.9	17.7	
5-29	--	--	Inner vessel cracked

used on vessel #4, except that in this series only construction grade sand was used. From the first shot it was evident that two bulges were developing and that the inner container was being driven further into the outer container. Table 2 lists the diameter of the bulges measured after every shot. The inner container moved a distance of 1 cm during the first twelve tests and remained in that position thereafter. Test 5-29 caused two rubber rings to be blown off and the inner vessel to crack. Figure 16 is a photograph showing these results.

Test vessel #6 - Rubber hardness 50-55 Shore A Duro

To prevent the rubber rings from moving and to provide access to the bottom of the outer container for the purpose of disassembly, a vessel similar to vessel #4 was prepared as shown in Fig. 17. The assembly of this vessel was as for the other vessels described earlier except for the following details. A 9.5 mm thick steel disc having three, 12.5 mm diameter steel rods screwed to it was placed in the outer container. The rubber disc and rings were then threaded to the rods

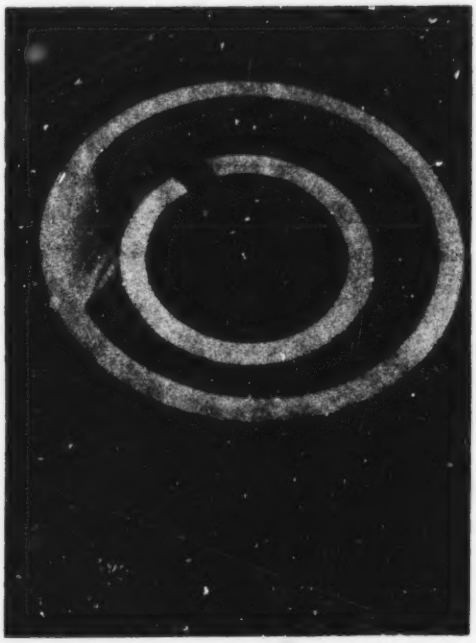


Fig. 16 - Result of detonating two cartridges of explosive confined in a steel pipe (Test 5-29)

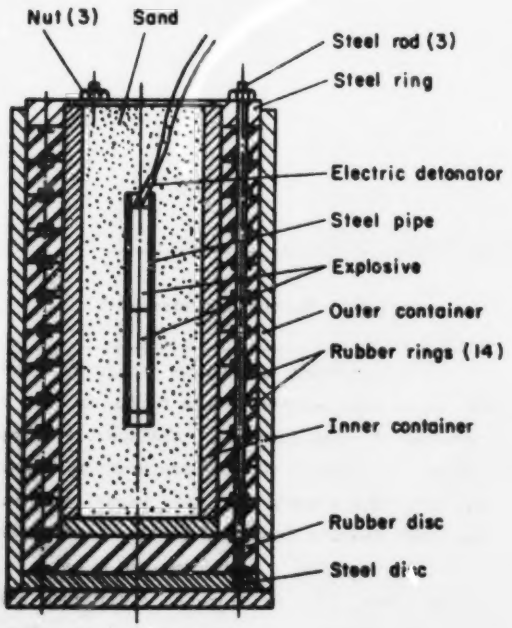


Fig. 17 - Cross-section of vessel #6

via their enlarged holes. Once the required number of rubber rings had been added, the inner container was pressed in and a 12.5 mm thick steel ring was bolted to the rods. Thus, the rods held the rubber components and the inner container sandwiched between the steel disc and the ring.

Testing proceeded as for vessel #5. Table 3 lists the diameter of the bulges as measured after every shot. The first two shots caused a 3 mm gap to develop between the steel ring and the inner container. Observing no further increase in the gap, the bolts were tightened after two more shots. Beginning with shot 6-10, in response to the forces exerted by the deforming rubber, the steel ring began to deform upward in the area between the bolts. This can be seen in Fig. 18. The gap between the ring and the inner

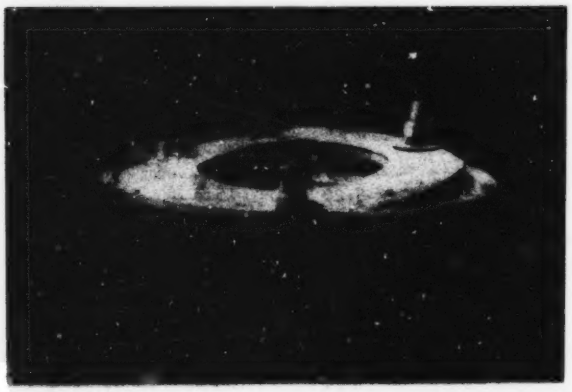


Fig. 18 - Deformation of steel ring (Test 6-12)

container due to this deformation increased from 1 cm to 6 cm from shot 6-11 to shot 6-13. During this period the top rubber ring was noticed to be split. Figure 19 shows the result of shot 6-14 which caused one of the steel rods to be partially pulled out. Shot 6-15 resulted in the steel ring with an attached rod and the immediate rubber ring to be blown off. These results are shown in Fig. 20. One of the other rods was also partly pulled out. The rod still attached to the ring had stripped threads at the end where it was bolted to the steel disc. The other two rods failed at the upper threads.

The second and third rubber rings were

Table 3 - Endurance test results for vessel #6

Test #	Diameter Top Bulge (cm)	Diameter Bottom Bulge (cm)	Comments
6-1	12.8	12.8	
6-2	12.9	12.9	3 mm gap*
6-3	13.1	13.2	
6-4	13.2	13.2	
6-5	13.3	13.5	Bolts tightened
6-6	13.5	13.7	
6-7	13.6	13.8	
6-8	13.6	13.8	
6-9	13.8	14.0	
6-10	13.9	14.2	
6-11	13.9	14.4	1 cm gap
6-12	14.1	14.6	2 cm gap
6-13	14.2	14.7	6 cm gap, rubber ring split
6-14	14.4	14.8	One rod slightly extracted
6-15	14.6	15.1	Steel and 1st rubber ring
6-16	14.6	15.1	blown off
6-17	14.7	15.3	
6-18	14.9	15.4	
6-19	15.0	15.7	
6-20	15.2	15.7	
6-21	15.2	15.7	
6-22	15.3	15.9	
6-23	15.5	16.0	
6-24	15.7	16.0	2nd rubber ring blown off
6-25	15.8	16.3	
6-26	15.9	16.4	
6-27	16.0	16.5	
6-28	16.3	16.5	
6-29	16.4	16.5	
6-30	16.5	16.7	
6-32	16.6	16.8	
6-35	17.1	17.0	3rd rubber ring blown off
6-40	17.7	17.3	
6-45	18.0	17.8	
6-50	18.4	18.0	Outside container deformed

*The gap is between the steel ring and the top of the inner container

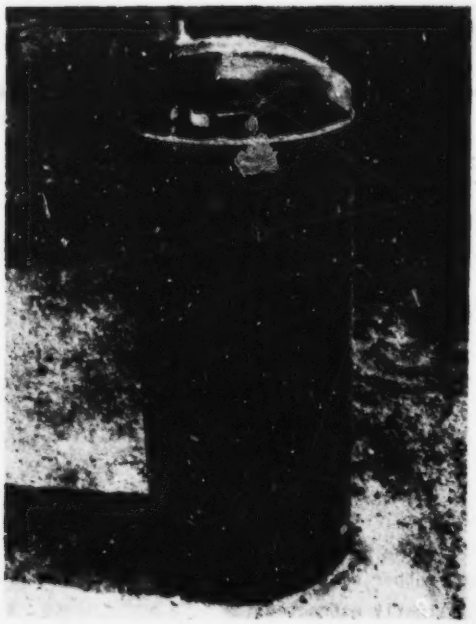


Fig. 19 - One steel rod partially pulled out (Test 6-14)

Fig. 20 - Steel ring blown off the container (Test 6-15)

blown off by shot 6-24 and 6-35 respectively. During the following tests the uppermost rubber ring migrated very little toward the top. The outside container also began to deform after shot 6-44 from an initial 27.94 cm diameter to 28.32 cm diameter when it was measured after shot 6-50.

Figures 21 and 22 show this vessel sawn in two. The two bulges are evident, as is the deformation of the bottom of the inner container.

Fig. 21 - Vessel #6 showing the two bulges

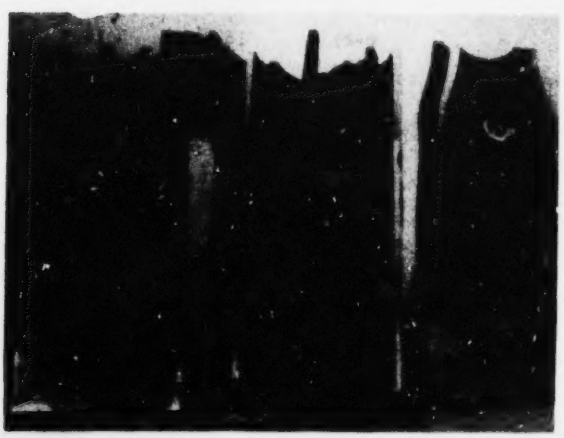


Fig. 22 - Details of vessel #6 cut in two

A multitude of fine cracks were easily discernible on the outside surface of this container. Note also, from Fig. 22, that the uppermost rubber rings are slightly separated from one another.

CONCLUSIONS

The testing proved that with two, 2.5 cm diameter cartridges of explosive confined in a steel pipe and imbedded in sand, the prototype vessels performed very well. This sample configuration is presently deemed satisfactory for the evaluation of the fumes evolved in the detonation of explosives. The endurance test results indicate that at least twenty-five to thirty-five shots can be performed without causing any distortion to the outer container, if the vessel is assembled with the softer rubber rings.

The use of a sacrificial inner container surrounded by rubber certainly protects the outer container. However, it must be installed in intimate contact with the rubber disc. It is also necessary to have the proper equipment to remove and install the liner when deemed necessary.

The sudden radial shock loading from the explosive causes a longitudinal expansion and movement of the rubber rings. This repetitive loading eventually causes the expulsion of the uppermost rings from the vessel. The design of vessel #6 was to evaluate the possibility of confining the rubber rings. However, the steel rods were too thin for the repetitive shock loading, and as a result, fractured after fifteen shots. It is conceivable that a thicker steel ring and disc and thicker rods would better confine the rubber rings. Absolute confinement of the rubber rings would increase the radial expansion, therefore it is recommended that the rubber rings not be confined.

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